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AN AUTOMATIC VEHICLE STATUS, LOCATION, AND ALLOCATION SYSTEM FOR SURFACE MINES

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AN AUTOMATIC VEHICLE STATUS, LOCATION, AND ALLOCATION SYSTEM FOR SURFACE MINES

by

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ABSTRACT

One of the main problems presently facing the efficient operation of a surface mine is the fact that the real-time status and position of vehicles in the mine are not known to the dispatcher. Further, the positions of vehicles are not being related to the existing route networks within the mine area to enable effective vehicle allocation. An Automatic Vehicle Location (AVL) system is recommended as a solution.

The system is composed of hardware (computer, input-output devices, positioning devices, etc.) and software (database management, best-route selection, etc.). The positioning system proposed in this application is a combination of, dead reckoning devices, and GPS satellite receivers. The combination of these positioning devices is to yield real-time 3-D vehicle coordinates accurate to a few meters. These vehicle coordinates are then related to an electronic map of the area and to a 3-D Digital Terrain Model (DTM). Consequently the link is secured between the real-time vehicle location, topography, route networks, and the dispatcher, enabling effective real-time route selection and other allocation decisions. A digital route map is an integral part of the AVL system. This map appears on a CRT visible to the dispatcher, illustrating all route networks in the mine domain, all vehicles linked to the system, and "best route" selections.

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SYSTÈME AUTOMATISÉ POUR REPÉRER L'ÉTAT DE LA CIRCULATION DANS LES MINES À CIEL OUVERT ET L'ENDROIT OÙ SE TROUVENT LES VÉHICULES EN VUE DE LEUR ATTRIBUER UN ITINÉRAIRE

par

E.J. Krakiwsky(1), A.B. Kempe(2), V. Srajer(3), H.A. Karimi(4)
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RÉSUMÉ

Un des problèmes principaux qui se pose à l'heure actuelle pour assurer l'efficacité de l'exploitation minière à ciel ouvert est lié au fait que le répartiteur ignore l'état de la circulation en temps réel et l'endroit où se trouvent les véhicules qui circulent dans le secteur exploité. De plus, le circuit des véhicules n'est pas planifié en fonction des réseaux routiers qui sillonnent le terrain de façon à attribuer les parcours les plus efficaces. Afin de remédier à la situation, on recommande l'utilisation d'un système automatisé pour repérer les véhicules (SRA).

Le système comprend du matériel (ordinateur, dispositifs d'entrée et de sortie, dispositifs de repérage de l'endroit où se trouvent les véhicules, etc.) et un logiciel (gestion de la base de données, sélection des parcours les plus appropriés. Le système de repérage automatisé que l'on propose est doté de dispositifs pour repérer les temps morts et de récepteurs satellites SPG. On a combiné ces trois dispositifs de repérage en vue d'obtenir des coordonnées 3-D en temps réel, précises à quelques mètres près. Ensuite, on établit un rapport entre les coordonnées des véhicules, une carte électronique du secteur et un modèle automatisé 3-D (MNT) à affichage numérique. Il

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s'ensuit qu'un lien en temps réel est établi entre l'endroit où se trouve le véhicule, la topographie, le réseau routier et le répartiteur. Par conséquent, on peut sélectionner les itinéraires les plus appropriés en temps réel et prendre les mesures qui s'imposent. Une carte routière à affichage numérique fait partie intégrale du SRA. Cette carte apparaît sur un tube à rayons cathodiques (CRT) que le répartiteur peut observer. Elle indique tous les réseaux routiers du secteur exploité, tous les véhicules branchés sur le système et offre une sélection des parcours les plus propices.

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INTRODUCTION

Overview of Surface Mining Operations

Surface mining involves the basic procedures of overburden removal, drilling and blasting, ore and waste loading, hauling and dumping and various auxiliary operations.

Loading of ore and waste is carried out simultaneously at several different locations in the pit and often in several different pits. Shovels and front-end loaders of various sizes are used to load material onto trucks. Loading times depend on shovel or loader capacity, digging conditions and truck capacity. Often trucks of different capacity are used at individual shovels, and, since loading times will vary considerably with truck capacity, queues will form at the shovels. An effective real-time dispatching system can reduce time spent in queues.

Hauling material from the shovels to the dump sites must be accomplished through a network of road links of various lengths and grades. In many Western Canadian coal mines, the topography is very rugged. Road links can become extremely complex, cover vast areas, and pass through extreme elevation changes. Often, segments are shared by more than one shovel-dump link, and because passing is not permitted, travel times are strongly influenced by the slover trucks. Many mines incorporate both on-road and off-road vehicles which haul specific materials. On-road vehicles are often used to haul coal from the pit along public road links to the stockpile or crusher, while off-road vehicles are restricted to the mine area. Thus, allocation of trucks to haul specific material from a specific pit or shovel becomes a complex problem.

Waste dumping and coal stockpiling is relatively straight forward. The queueing of trucks will also occur at these sites since only a limited number of trucks can dump at a given time. Dump sites must be continually relocated as they reach design volume limits.

Obviously efficient mining operations are strongly dependent on the proper allocation of trucks to shovels and the respective allocation of trucks along the appropriate road links and to dump sites. Due to equipment breakdowns, varying digging conditions and truck capacity, and even coal blending considerations, frequent truck re-allocations are required to maintain an efficient operation. Presently, the shift foreman, in order to maintain an up-to-date awareness of the truck-shovel operations in the mine, must circulate continually around the mine site observing queue lengths, digging conditions, etc., at each shovel and re-allocate trucks as required. A computerized dispatching system incorporating vehicle status and location information can be used to perform this task more effectively.

The often harsh Canadian climate creates many problems in conducting an efficient surface mining operation. Fog, driving rain, sleet and snow cause visibility problems for all vehicles in the mine. Visibility is often restricted to only a few meters making vehicle driving and manoeuvering extremely dangerous. Trucks in particular must reduce their speed considerably, and in areas of restricted manoeuverability trucks are forced to stop for fear of collision with other vehicles. For this reason, a vehicle location-dispatch system must yield accurate real-time vehicle position. In the event of excessive moisture, some haul roads may contain grades too steep for trucks to climb or safely descend. An electronic map and dispatch system would enable the dispatcher to identify routes with problem segments, and detour vehicles around these trouble spots if possible.

Auxiliary equipment used in the mine includes bulldozers, graders, water and sand trucks, front-end loaders, service trucks, garage facilities, etc. All of this auxiliary equipment contributes extensively to the mining operation but their importance is sometimes overlooked. Locating and subsequently allocating such equipment throughout the mine is another very important function of an efficient dispatch system.

Problem of Vehicle Status, Location and Allocation

It is generally accepted that the principal objectives of any computerized dispatching system are to maximize shovel-loader utilization (i.e.

minimize shovel idle time) and maximize truck utilization (i.e. minimize truck queue time) [White et. al., 1982]. In order for the system to accomplish these objectives three basic functions: vehicle status, location and allocation, must be incorporated into the system. Dispatching is a dynamic operation that requires continuous monitoring of vehicle status and location to determine the optimal vehicle allocation, including best route selection, shovel and dump site selection.

To effectively position equipment throughout the mine, an instantaneous status report for every vehicle in the mine must be available to the dispatcher. This status report would include such conditions as queueing, loading, on route to dump, on route to shovel, and breakdown. This status report will be used by the dispatcher to make decisions concerning allocation of personnel and equipment. For example, if a shovel breaks down, trucks can quickly be redirected to a different shovel, distributing the numbers of trucks to suit the different materials, routes, etc. The implementation of a status report transmitted to the dispatcher is certainly a necessity of an efficient dispatch system.

In addition to vehicle status, an effective dispatch system must have knowledge of the real-time position of vehicles in the mine and at facilities outside the mine such as a remote stockpile and loading system. One of the main problems presently facing the efficient operation of a surface mine is the fact that the real-time position of vehicles is not known to the dispatcher. To make truly effective decisions concerning allocation, the dispatcher needs to know the location of all operating vehicles within the mine domain. For example, trucks originally designated to a shovel where a queue is presently forming, could, while "on route to shovel", be efficiently redirected to another shovel via the "best route" only if the real-time location of the trucks is known to the dispatcher.

For effective use of dispatch software, such as a "best route" algorithm, the real-time position of vehicles must be related to the route networks within the mine domain. Through analysis of the position of vehicles, the dispatch software can conduct real-time allocation decisions

such as the re-routing of an individual truck from its present shovel destination to reduce queueing at that shovel. To accomplish this, however, the real-time position of vehicles must be related to the existing route networks, including all the vehicles route alternatives before it becomes committed to a particular route.

A compounding problem is that the topography in the mine area is not related to the existing route networks and to the real-time position of vehicles in the mine. In order to accomplish "best-route" selection (especially in mountainous regions), the topography of the routes must be considered and the obvious effect it has on vehicle travel time.

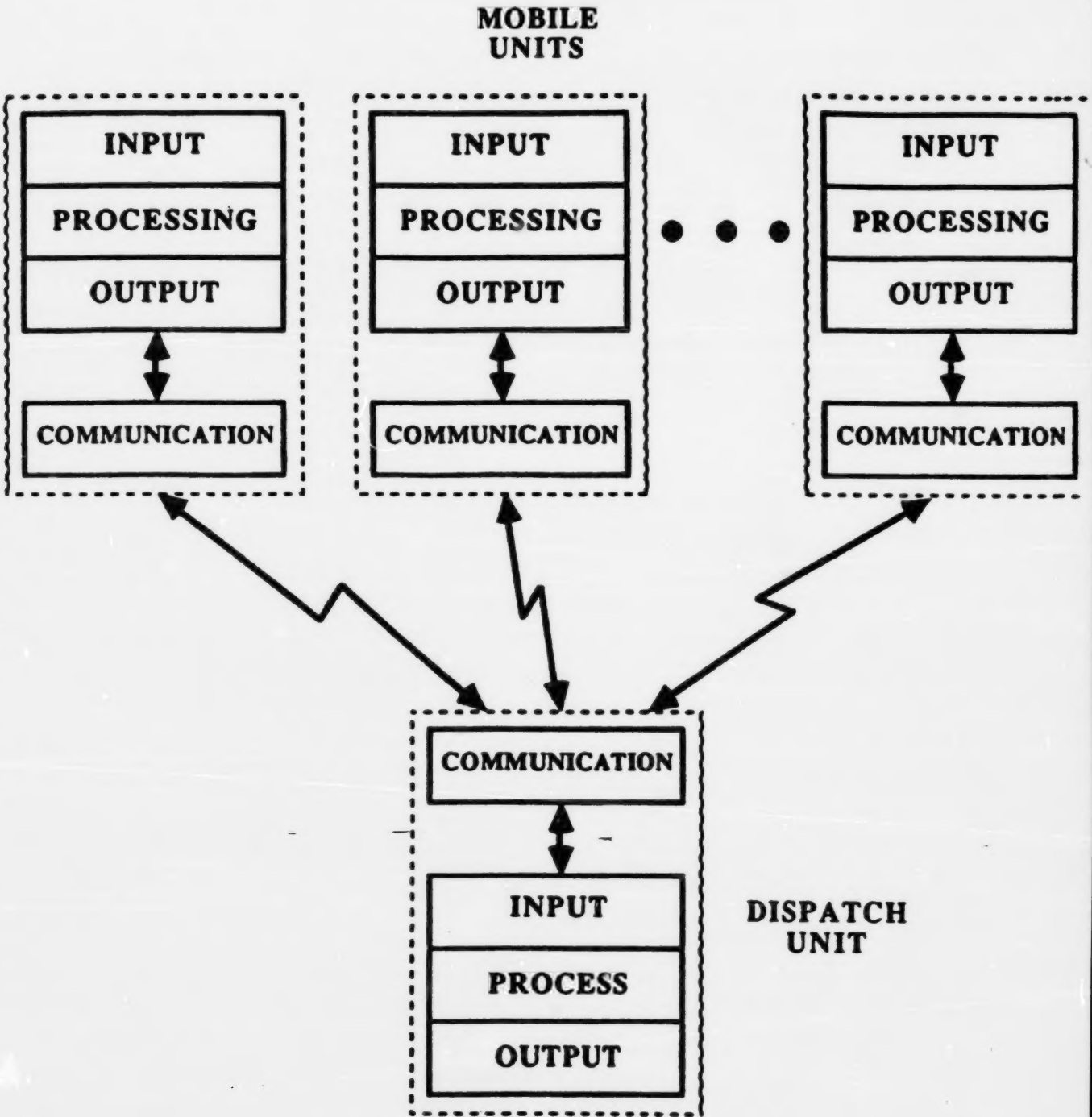
Clearly, there is a need to obtain real-time vehicle status and location information and relate this to route networks and topography within the mine. Many dispatching systems yield real-time vehicle status information, however, few yield real-time vehicle location. Systems using "sign post" positioning yield position updates at only selected locations. This results in position "outages" between posts making these systems inadequate. The automatic vehicle location system (AVL Mining^{TM} System) described in the following sections is a unique system. This system yields real-time vehicle status and location information and further relates this information to an electronic map and 3-D Digital Terrain Model (DTM) of the area. Together, the electronic map and DTM, contain information on all route networks including route topography. This ability to relate real-time vehicle status and location information to the route networks and topography makes this a very effective dispatching and allocation system.

THE AUTOMATIC VEHICLE LOCATION (AVL) MINING^{TM} SYSTEM

Overview

The AVL Mining^{TM} System is comprised of a central dispatch unit and many mobile units (Figure 1). Each mobile unit receives position sensor input, processes data, and prepares output for transmission. In addition,

FIGURE 1. AVL MINING™ SYSTEM OVERVIEW



each mobile unit is equipped with a communication unit for transferring information to and from the dispatch unit.

The dispatch unit also receives input, processes data, and prepares output for transmission or other purposes, and has a communication unit for the transfer of information to and from mobile units.

System Functions

Figure 2 depicts the AVL Mining™ System specifically designed for application in surface mining. Illustrated in detail is the dispatch unit, a mobile unit and the communication link.

Data input from each mobile unit is as follows:

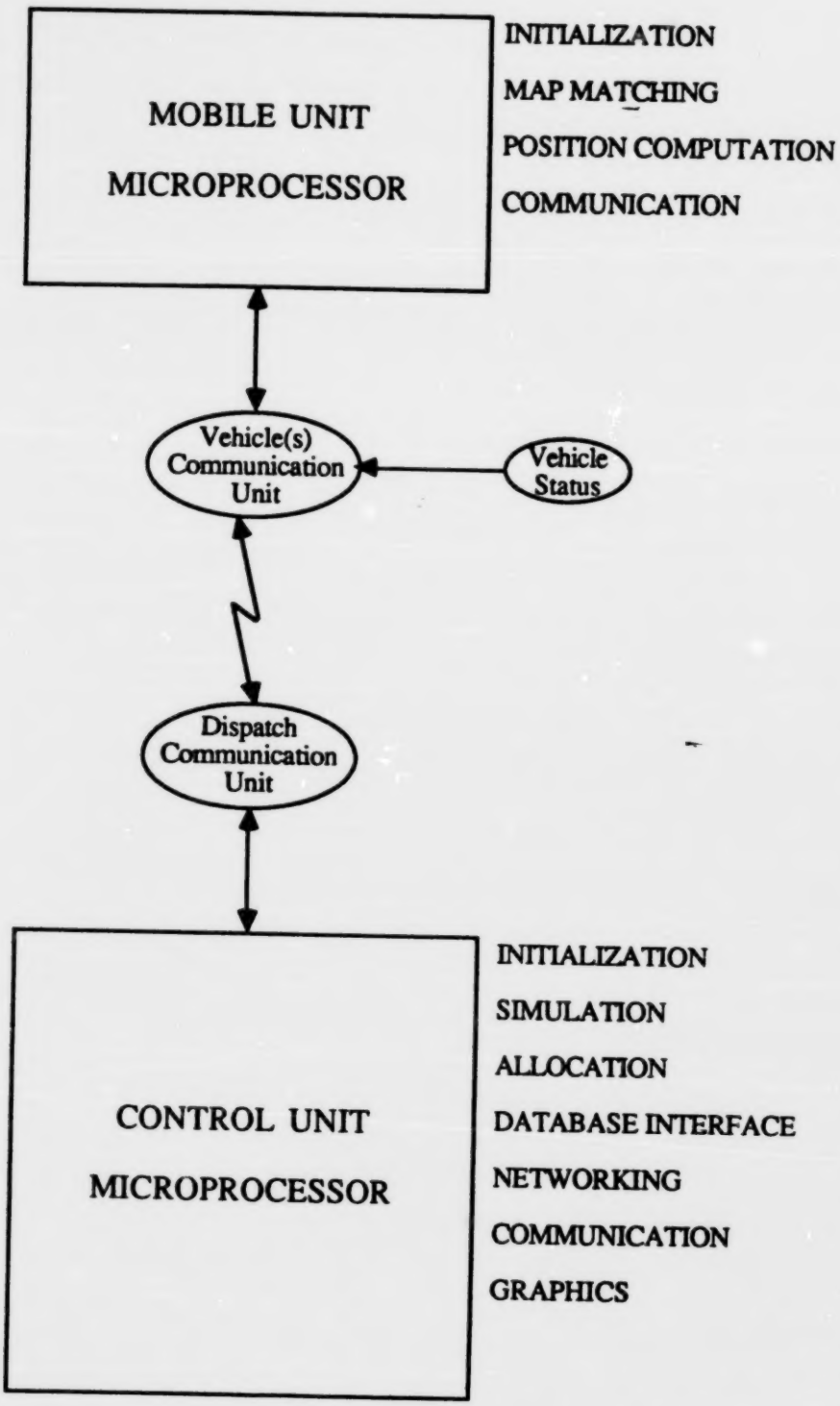
a) vehicle status report, entered by means of a keypad; and
b) real-time vehicle position, resulting from a combination of one or more positioning sensors.

Data from the positioning sensors is input to the microprocessor, while the status report data is input directly to the communication unit, ready for transmission to the dispatch unit.

The operations performed in each mobile unit include operation initialization, calibration of sensors, computation of real-time positions, map matching, and transferring information to and from the dispatch unit.

A display device is used in each mobile unit to enable checking of information sent from the mobile unit and enable confirmation of instructions received from the dispatch unit. Voice synthesis (output) will be used primarily for transferring urgent information to the operator of the mobile unit to ensure that information is not missed, and to retain the safe efficient operation of the vehicle. For example, when two vehicles are approaching one another and visibility is limited to only a few meters, a voice sythesizer would first acknowledge the approaching vehicle to each operator, then simply "call-out" the relative tangential separation distance between the vehicles (at a predetermined interval) until they have safely

FIGURE 2. AVL MINING™ SYSTEM COMPONENTS



passed one another. The operator would refer to the display device only if the distance was not heard.

The dispatch unit is responsible for overall information management, allocation and dispatching. The only manual input to the unit is through operator interaction by means of:

a) a keyboard; and

b) a mouse and/or light pen.

The tasks performed by a dispatch unit include operation initialization, simulation, best-route selection, allocation dispatching, Digital Terrain Model (DTM) data management, and communication with mobile units.

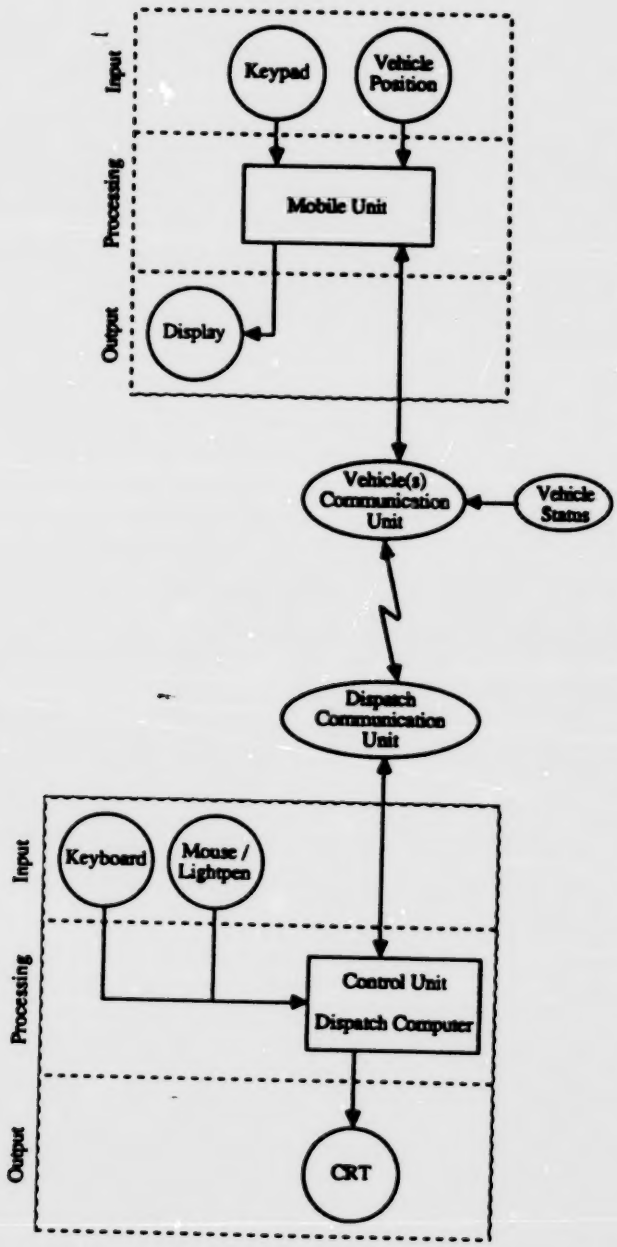
The only output device necessary for the dispatch unit is a Cathode Ray Tube (CRT) display for viewing the 2-D projected DTM map of the entire mining area, including remote facilities. The real-time position of all vehicles with mobile units is superimposed on the DTM along with pertinent shovel and vehicle allocation information. Note that a 3-D DTM map exists and is used throughout, especially for "best-route" selection, however, only the 2-D projected DTM map is used for display on the CRT to reduce the complexity of the 3-D image. The dispatcher does not need to visually observe the third dimension, its contribution is accounted for through system software.

HARDWARE

System Integration

Hardware components of the designed AVL Mining^{TM} system are shown in Figure 3. The keypad necessary for each mobile unit is a customized product based on specific functions the vehicle operator requires for efficient interaction with the dispatch unit. Obviously, the necessary keys for a shovel will differ from those of a truck, grader, etc.

FIGURE 3. AVL MINING™ SYSTEM
HARDWARE COMPONENTS



The mobile unit positioning sensors are described in detail in the next section.

The mobile unit processor must be as compact as possible for obvious reasons. This dictates the employment of a microprocessor, either a custom design or simply a microcomputer. A small microcomputer with appropriate speed and capacity is proposed here. The criteria for the choice of a microcomputer should include the ability for present and future expansion. Therefore, a PC compatible system, such as the Little Board™ /186, manufactured by AMPRO, is recommended. Some of its characteristics include: 8 MHz, 80186 CPU with DMA and counter/timers, 512K RAM and 2 RS 232C serial ports. The position computation cycle time is approximately 1 second, therefore this system is sufficient.

The display device in each mobile unit is either a Liquid Crystal Display (LCD) or a Light Emitting Display (LED), which is mainly used for checking sent text information and confirming received information. The voice synthesizer presently supports only a limited number of words and phrases which must be built into the system. Thus, voice synthesis would only be used for relaying urgent messages and could not replace standard radio communication. The voice synthesizer is an off-the-shelf hardware-software system. In the future, a flat panel display will also be installed in mobile units to display map data as well as text.

The PC/AT compatible (equipped with a keyboard, mouse, and/or lightpen), with a high capacity hard disk drive and floppy disk drives, is proposed for the dispatch unit computer.

The CRT display unit, along with an appropriate graphics board at the dispatch unit, must include the folloving characteristics: high resolution, color graphics (at least 16 colors), and high speed graphics.

The data communication unit in each mobile unit is an off-the-shelf modem with a minimum data transfer rate of 1200 baud. The data communication unit in the dispatch unit, having the same data transfer rating as that

for the mobile unit, is interfaced to a separate microprocessor. The required microprocessor is a PC (XT/AT) compatible with a hard disk and a floppy disk drive without a keyboard and a CRT display. The Westar Production Monitor and Control System (PMCS) is an implementation of this system [Westar Engineering]

Positioning Sensors

The two basic categories of positioning sensors incorporated in the AVL Mining™ positioning system are Dead Reckoning (DR), and satellite positioning.

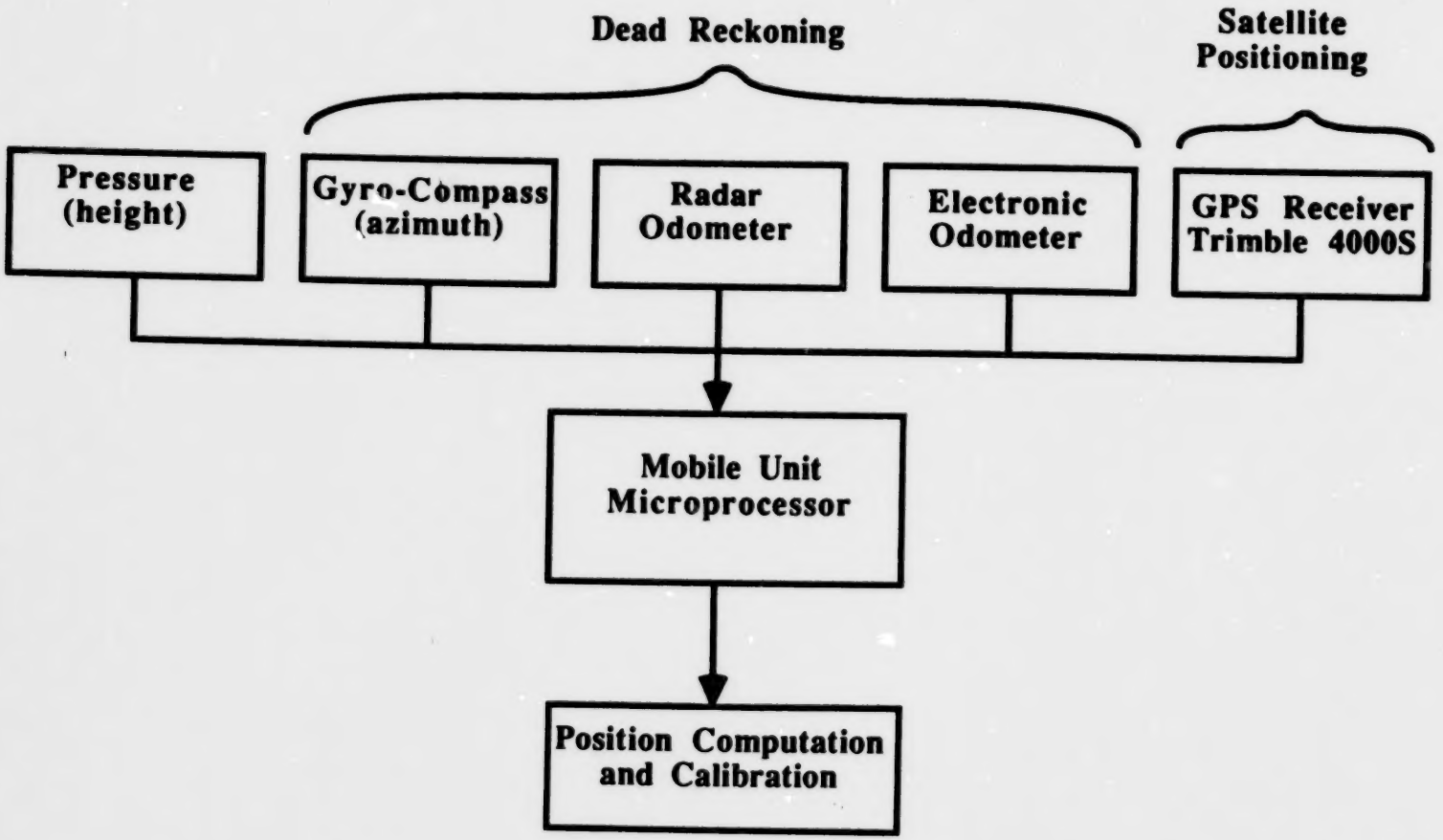
The DR sensors include height sensing, speed sensing, and direction sensing.

Height sensing is accomplished using an AIR Intellisensor precision altimeter. This precision aneroid device is fully temperature compensated and has a resolution of 0.1 mb. This means the sensor can reliably measure vertical movement to 0.8 m. The device is microprocessor controlled and provides digital output in units of elevation (metres) or pressure (millibars). It can be calibrated against any known altimeter or a known elevation to provide true elevation. Extensive survey experience has proven a sensor accuracy of about 2 m in the majority of cases.

All dead reckoning systems require position initialization. Initialization can be accomplished simply by means of a button, pressed by the operator when the vehicle is located at a known position. Obviously, the position initialization would include a height initialization as well. In addition, an Intellisensor would be installed at the dispatch centre at a known elevation, enabling altimeter re-calibration by vehicles at the centre. Experience has shown that re-calibration every hour of vehicle use is adequate to maintain the desired accuracy.

Speed sensing is provided by two independent devices. One device, a Nu-Metric precision odometer, counts revolutions and fractions of revolutions of a non-driving wheel. A microprocessor converts this into

FIGURE 4. POSITIONING SENSORS



speed using a simple calibration routine. Nu-Metrics have been used for electronic survey chaining. On hard surfaces, they provide accurate speed (or distance) measurement to one part in one thousand.

Because the accuracy and reliability of a precision odometer in a mining environment is unknown, a Doppler speed log will also be incorporated to measure vehicle speed. This device is also an off-the-shelf product and retails for less than $1000. They are used extensively on farm machinery, and display speed in units of kilometers and tenths of kilometers per hour. Eventually, substantial field evaluation will enable selection of one of these two devices as the standard speed sensor.

Similar to the height sensor, the speed sensor is calibrated against known distances travelled between initialization and check points. It is also proposed to use dual Doppler speed logs to sense change in direction.

Heading sensing is provided by a slaved directional gyro. Slaving is provided by a flux valve. The AIM 400 system, an off-the-shelf avionics product utilized in aircraft auto-pilot systems, is recommended. The gyro is electric, requiring a 12 VDC power supply. Flux valves are magnetic compasses which sense the direction of the earth's magnetic field by inductance through their windings. They do not align or point in the manner of ordinary compasses and are considered accurate to approximately 1.5 degrees. They are, however, affected by magnetic variations as is any compass, and they also must be "swung" after installation to account for the magnetic effect of metal in the vehicle itself. The long term stability of the flux gate compass is excellent, however, in the short term, it is still affected by proximity to other vehicles and steel structures in general.

The directional gyro drifts over time and thus has to be reset at regular intervals. The short term stability of the directional gyro is excellent, yielding an accuracy in the order of 0.5 degrees. The use of dual Doppler speed logs for detecting change in azimuth could eliminate the requirement for a gyro.

There are true north seeking gyros available which are used extensively for marine applications, but they are large and very expensive.

In certain mine environments the flux gate compass may be adequate without a directional gyro. The validity of this statement will be established in the first year of operation.

Similar to the speed and height sensors, heading sensors must also be calibrated during initialization and at check points.

The accuracy of a dead reckoning system is affected by two factors. First, sensor limitations and sensor drift contribute to position error (increasing with time from calibration) and second, map matching reduces or eliminates position error by comparing computed position with "observed" position.

For example, over a 10 km distance, an along track error of 10 meters would be expected from a system providing 1:1000 accuracy. An across track error of 262 metres would be expected (1.5 degree accuracy) and a height error of 2 meters would be likely. These figures assume the sensors are properly calibrated and operating within specifications. They also assume that the errors are systematic and not random. Map matching reduces these errors by comparing a computed position with the reality of the digital map. For example, if the vehicle is "constrained" to be on a road (at least in certain areas), heading errors are reduced to the width of the road. If the heading sensor observes a change of direction corresponding to a known change of direction for the section of road, this enables a position update and essentially all accumulative position error is eliminated.

The height sensor is used similarly, but its usefulness depends largely on the topographical relief found in the mine area.

The satellite positioning sensors incorporated into the positioning system are Trimble 4000S Global Positioning System (GPS) satellite receivers. In order to fully utilize the GPS in real-time, a receiver configuration is incorporated which uses kinematic relative positioning [Schwarz et. al., 1987]. With a stationary receiver located at the dispatch centre all mobile receiver positions are determined relative to the stationary receiver. Using this method a real-time position accuracy of 0.5 - 1.5

m is attainable. Because of the present limited satellite constellation, GPS positioning technology must be used in conjunction with DR devices, which constitute the main positioning system. GPS could play a more important role in the future once the full constellation of satellites is available (early 1990's).

Measurements from all positioning sensors are input into the microprocessor resident in each mobile unit. The dispatch unit, via the data link, receives the result of calibrated and computed real-time positions which are determined by each mobile unit microprocessor.

SOFTWARE

Mobile Unit Softvare

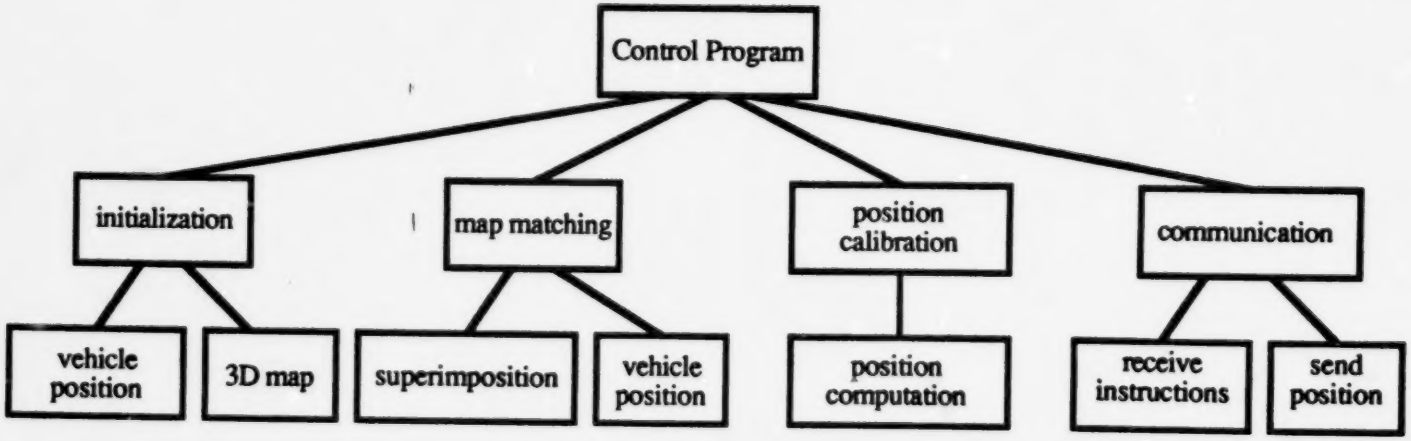
The software required for each mobile unit microprocessor is composed of initialization, position calibration and computation, map matching, and communication modules (Figure 5).

Initialization is the process of "setting up" operations. Ideally this would be done at the start of each shift. It essentially transmits the mobile units initial position to the dispatch unit. Consequently the mobile unit will start each shift by transmitting its calibrated real-time position, status report, etc. This transmission of information will be conducted at a predetermined time interval or when a request is made by the dispatch unit.

The map matching module tracks the mobile unit's real-time positions. Through this technique, real-time positions of the mobile unit are correlated to the DTM map of the mine area. At certain nodes in the mobile units tracks, coordinates from the DTM map are used to accurately define the units position, and enable a position update.

A communication module is used to transmit information (e.g. position, instructions, etc.) between the dispatch unit and mobile unit.

Figure 5. AVL MINING™ SYSTEM MOBILE UNIT SOFTWARE



Dispatch Unit Softvare

The software required for the dispatch unit of the AVL Mining™ System is composed of initialization, simulation, allocation-dispatching, communication, DTM data management and graphics modules (Figure 6).

The simulation module receives information on each mobile unit's real-time positions and status and uses this information to simulate an optimal mining operation based on status and location only.

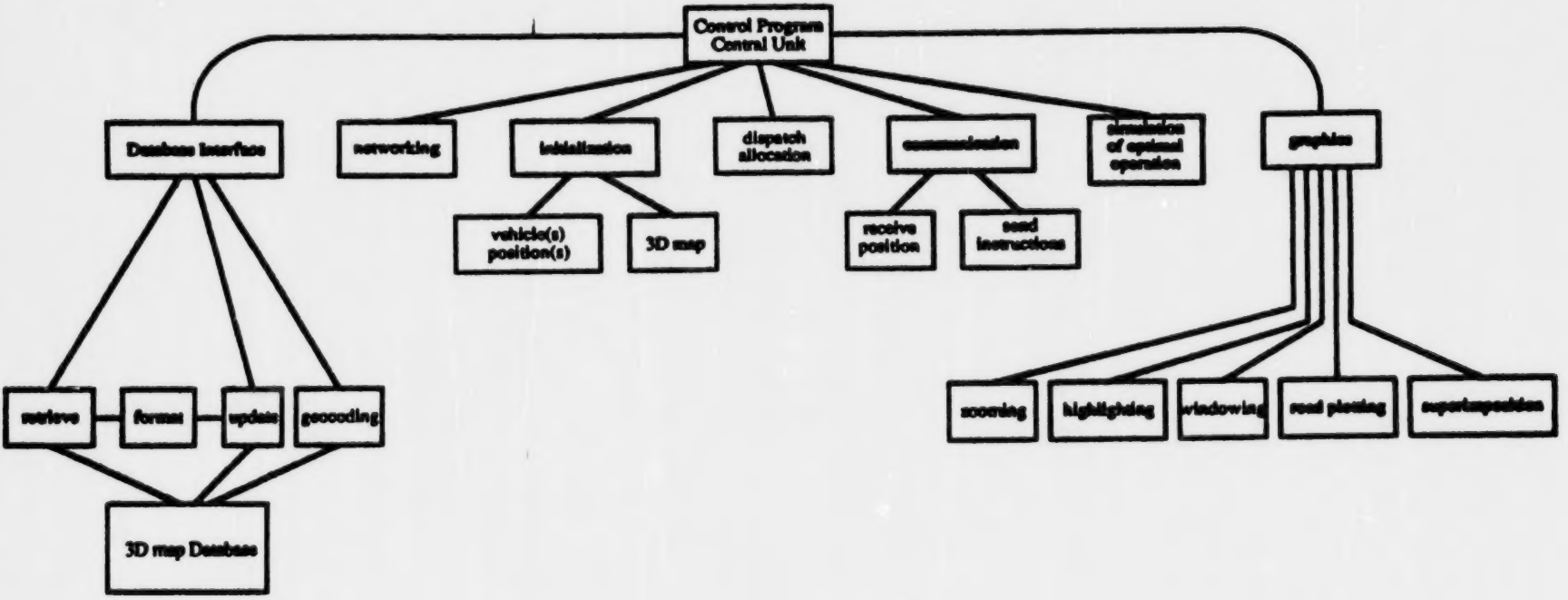
The allocation-dispatching module takes each mobile unit's real-time position, status, and simulation results and converts this information into real-time vehicle allocation decisions. The module accomplishes this through application of a "best route" algorithm which simply determines the shortest distance between the vehicles present location and the desired destination. Several algorithms have been developed for the standard node to node shortest distance problem. Once appropriate vehicle allocation decisions have been made, they must then be converted to routing instructions to be transmitted to the appropriate mobile units. This is one of the more important roles of the AVL Mining™ System and thus the effective performance of this module is crucial.

The communication module, similar to that of the mobile unit's, transmits information between itself and the mobile units.

The DTM data management module is an interface between the control program and the physical storage of the DTM database. Its functions include retrieval, formatting, updating and geocoding of the DTM database.

The graphics module is a collection of subroutines to handle graphics output for display. Operational functions include zooming, highlighting, windowing, road plotting and superimposition of each mobile unit's position on the display.

FIGURE 6. AVL MINING™ SYSTEM DISPATCH UNIT SOFTWARE



CONCLUSIONS AND RECOMMENDATIONS

In this paper, an overview of operations in a surface mine is presented, in an attempt to recognize inefficiencies and problems that could be eliminated through the implementation of an effective automatic vehicle dispatch system. The two main problems recognized are the formation of queues at shovels and alternatively shovels sitting idle waiting for trucks. Effective vehicle allocation through an automatic vehicle dispatch system is seen as a means of minimizing truck queue time and maximizing shovel utilization. In addition, an automatic dispatch system would yield other benefits as follows:

(1)- reduction of distance travelled through optimal route selection,

(2)- improved response to emergencies and delays, such as vehicle breakdowns, shovel repositioning, etc.,

(3)- reduction of production differences, common with manual dispatching techniques,

(4)- improved safety through accurate vehicle location,

(5)- improved scheduling resulting from accurate vehicle location,

(6)- instantaneous status reports available on demand to management.

The AVL Mining™ System designed by AVL Automatic Vehicle Location Systems Ltd. of Calgary Alberta, described in this paper is intended to reap the above mentioned benefits. This system is recognized for its ability to achieve the high standard of accuracy necessary, and because it satisfies all the functional requirements demanded of the system, while remaining very cost competitive with other systems.

Development, implementation, and component testing must be undertaken to eliminate unnecessary sensors, improve graphics capabilities, and optimize software components. The implementation of such a system in Canadian mines would substantially improve the operating efficiency of our mines and further improve Canada's competitiveness in world coal markets.

ACKNOWLEDGEMENT

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